R&D on the Polarized Electron Source for eRHIC

(the Linac-Ring option)

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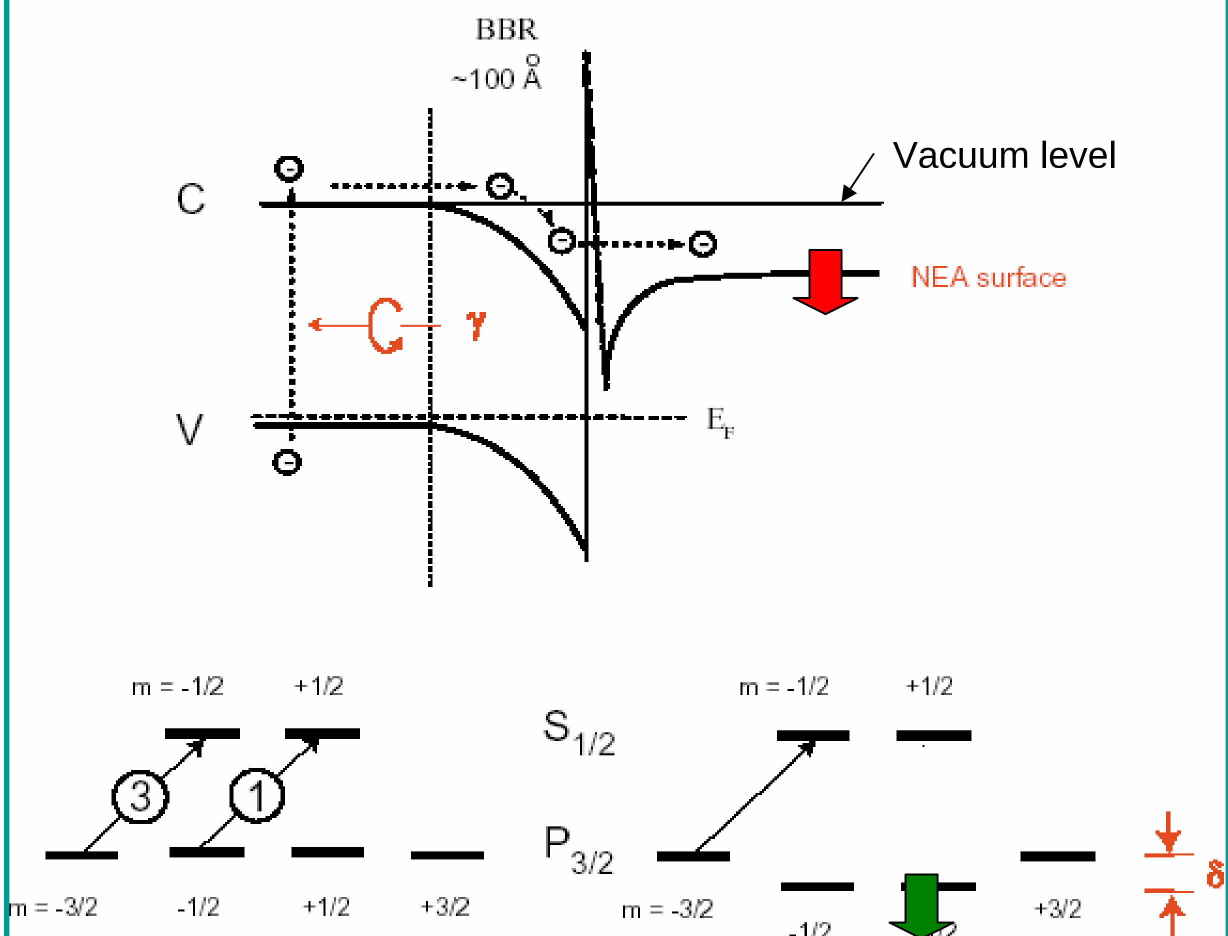
OUTLINE

- Photoemission process
- Polarized source requirements for the Linac-Ring eRHIC
- Options for the laser system and the injector
- Critical R&D for Linac-Ring eRHIC polarized source
- Proposed R&D at MIT-Bates
- Summary

Photoemission from GaAs based photocathode



Bulk GaAs: Pol < 50%

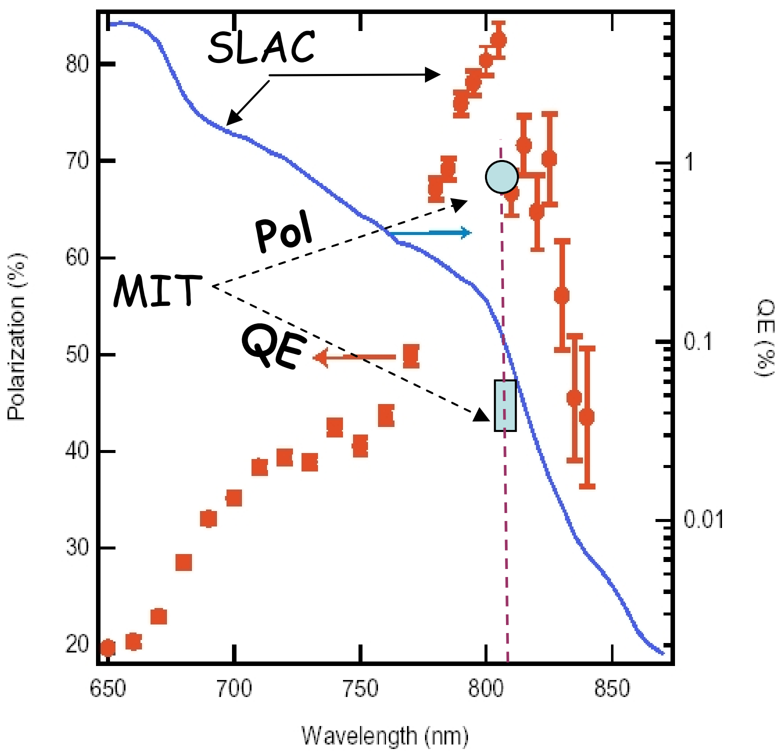
Strained GaAs: Pol > 70%

High polarization: → Low QE

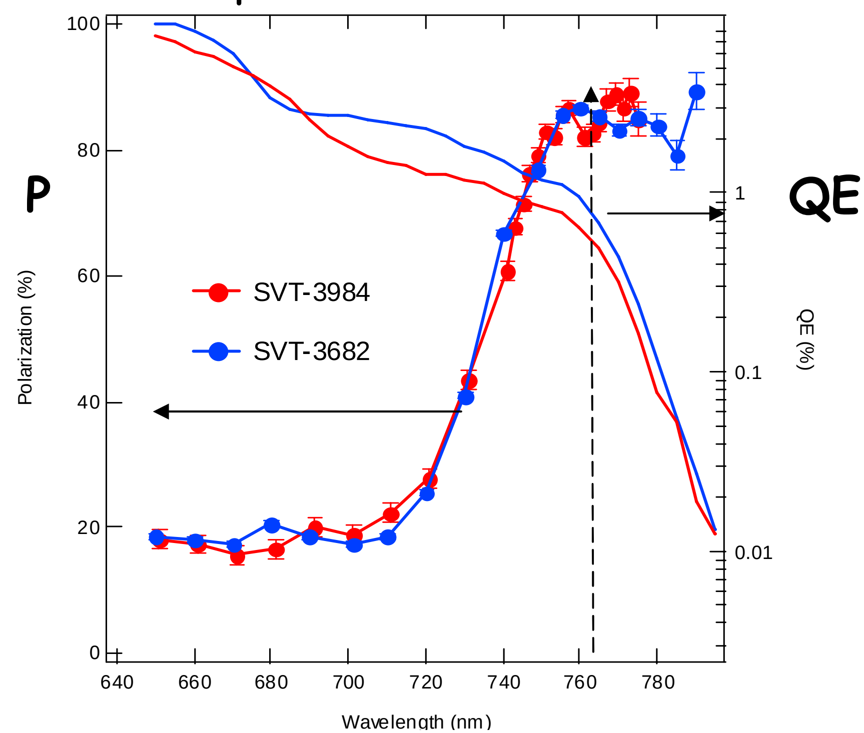
High polarization Photocathodes

1. High Gradient doped GaAsP photocathode
2. Superlattice photocathodes

HGD strained GaAsP



Superlattice



Peak pol~75%, QE- 0.01- 0.1% at 810 nm

Peak pol~85%, QE- 0.1- 0.3 % at 765 nm, better P and QE, but harder to tame.

A Polarized Electron Source

- A GaAs based photocathode in a UHV diode gun structure
- Capable of functioning at HV 100-500 kV.
- Provisions for heat cleaning (~ 600 C) and to achieve NEA (Cs, O_2, NF_3) condition.
- A laser system with circularly polarized photons of correct λ.
- An injector to transport and to accelerate electron beam.

•A best possible load lock system is essential for rapid photocathode replacement and better UHV conditions.

Linac-Ring specification for the electron beam

Beam rep-rate [MHz]	28.15
RMS normalized emittance [μm]	5- 50
Bunch length at cathode [ps]	100-200
Electrons per bunch	$1\text{-}10 \times 10^{10}$
Charge per bunch [nC]	1.6 -16
Average e-beam current [A]	0.45
Peak current [A]	135

$$\boxed{I(mA) = \lambda(nm)\,P_{laser}(W)\,QE(\%)/124}$$

Sample	QE (%)	Polarization	λ (nm)	$P_{laser}(W)$	$P_{peak}(kW)$
Bulk	2	40	780	> 40	12
Strained	0.05	75	810	> 1400	420
Superlattice	0.1	85	760	> 750	210

PES Parameters for the Linac-Ring EIC

Comparison with other photoemission sources:

- eRHIC linac ring : 450 mA, >75% pol., synchronized bunches
  - J-Lab: CEBAF: 100 uA polarized 75% pol.
  - J-Lab: FEL: 10 mA, unpolarized
  - Bates : 2 mA at 70% with stacking to 200 mA
  - Cornell, ERL: Goal: 100 mA, no polarization
  - eRHIC: ring-ring: 20 mA peak, high P for storage ring

This average current is ~ 3 orders of magnitude more than what is produced by today's accelerator based polarized sources (J-Lab, Bates and Mainz). At MIT-Bates peak currents of ~60 mA in the test beam line have been produced. <u>The beam emittance requirement for linac-ring is modest.</u>

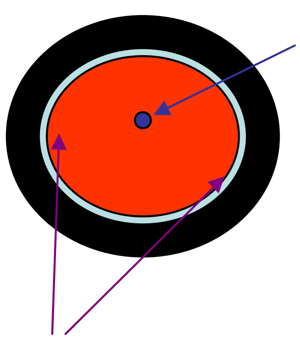
PES Parameters for the Linac-Ring EIC

How to achieve this?

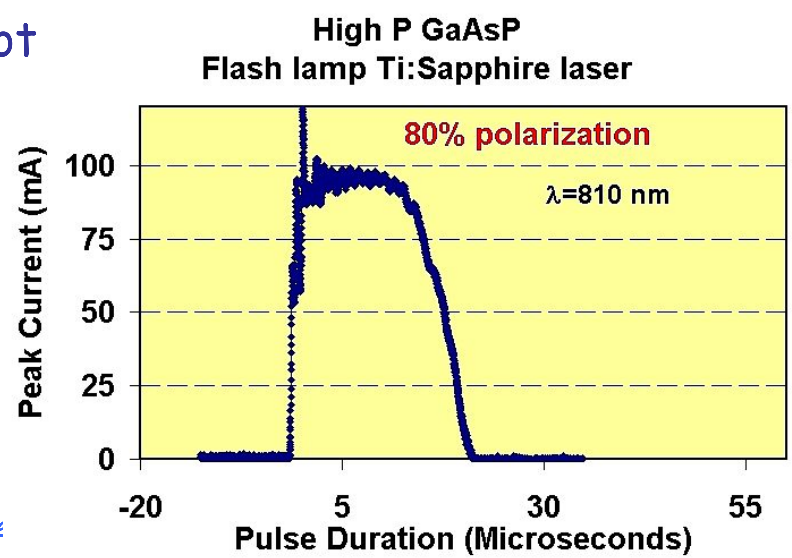
Assuming scaling law holds in photoemission:

- With a laser spot size ~ 3 cm^2, QE= 0.1% for high P will need ~ 700 W laser for 1/e lifetime. Using the best cathode lifetimes at J-lab with 100-200 μA average currents and ~0.2 mm laser spot, and extrapolating to the 450 mA current, about 1 week of continuous beam can be maintained (P. Hartman, C. Sinclair of Jefferson-Lab, EIC workshops).

- Crossing new territories in polarized photoemission (peak and average currents and synchronization) that requires comprehensive R&D.

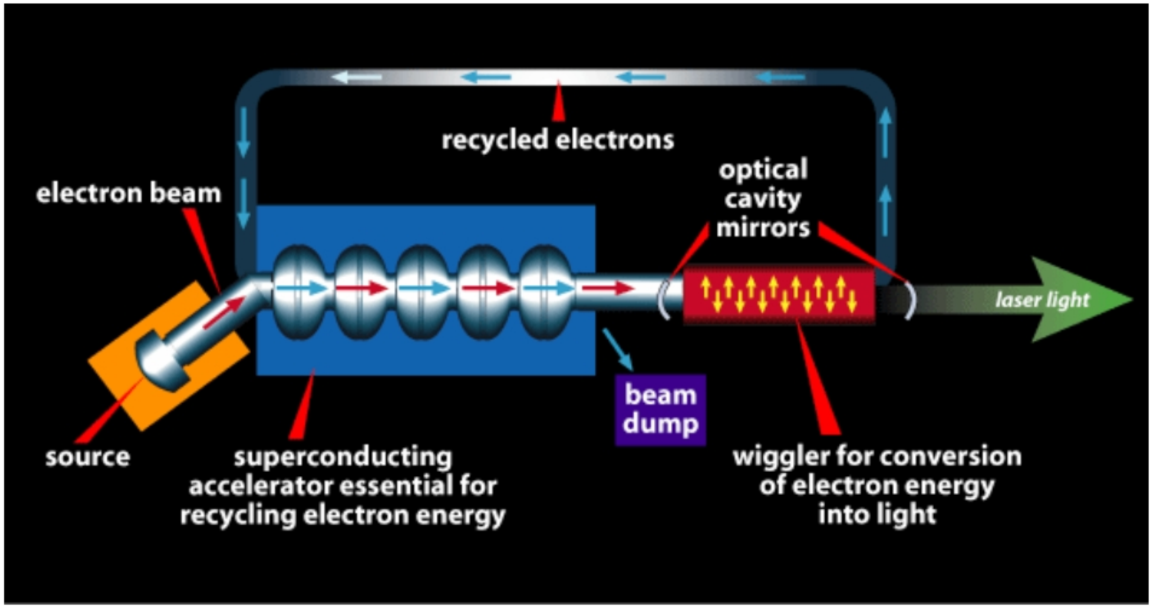


eRHIC

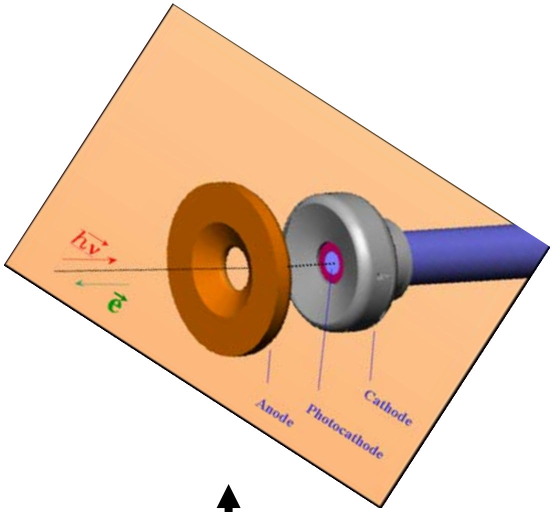


MIT data, 2002

Polarized Source for eRHIC linac-ring design



ERL-FEL to produce KW of IR laser for Polarized source.

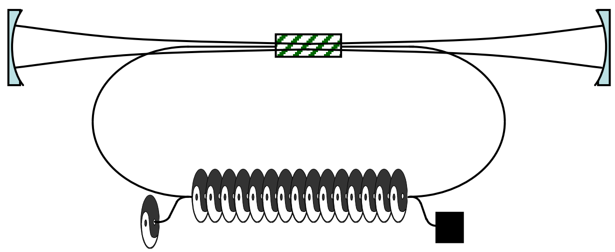


Polarized source for Linac-ring eRHIC

Using scaling law from current J-lab charge/cm^2 and an FEL laser, need to use a large area photocathode.

Laser source for linac-ring polarized source

1. Dedicated ERL FEL



Photon wavelength	850-750 nm
Polarization (left/right)	circular
Laser power [W]	1-2 kW
Mode of operation	CW
Rep-rate	28.15 MHz
μ-Pulse duration [ps]	100 - 200
Peak power [kW]	170 – 8,440
Stability Pulse-to-pulse	< 0.1%
Long term	< 1%

Adequate laser power, tunable wavelength with 28.15 MHz structure

2. Multiple diode array lasers

60 W per unit at 810 nm

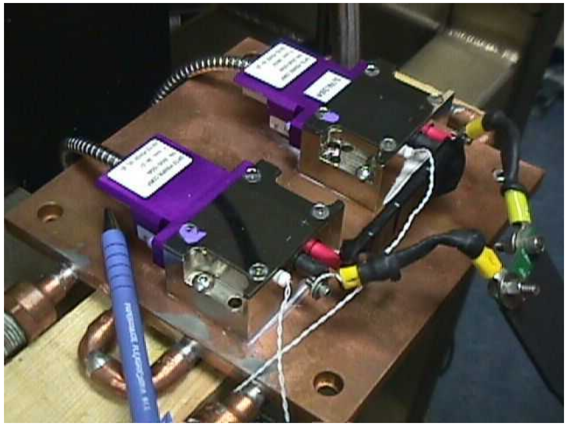
In use at MIT-Bates

Multiple systems needed

DC, No RF structure

Need chopping and bunching,

Excellent for initial tests



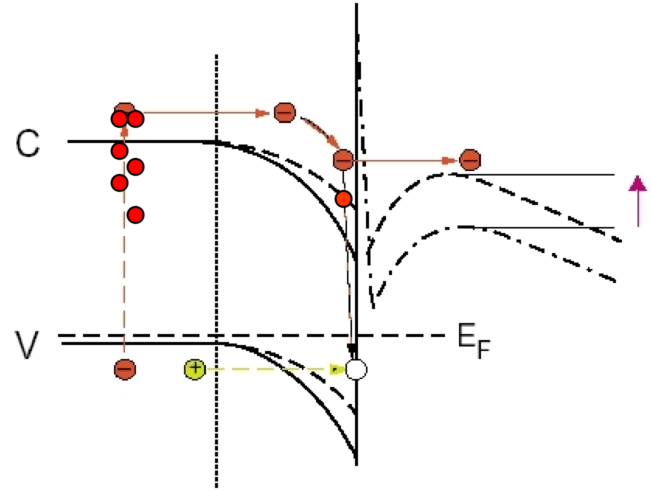
Areas of R&D

- Scaling law is assumed, (does it work)??
- Surface charge limit
- Heat dissipation in the photocathode
- Large photocathode gun (or multiple Photocathodes)
- Emittance modeling
- shape of cathode? (multiple photocathodes around a ring, difficult modeling)
- UHV, near XHV for lifetime
- Load lock gun
- Laser systems
- Injector pulse compression (sub-harmonic bunching, chopping)
- Synchronization

There is an abundance of critical R&D issues that needs to be addressed.

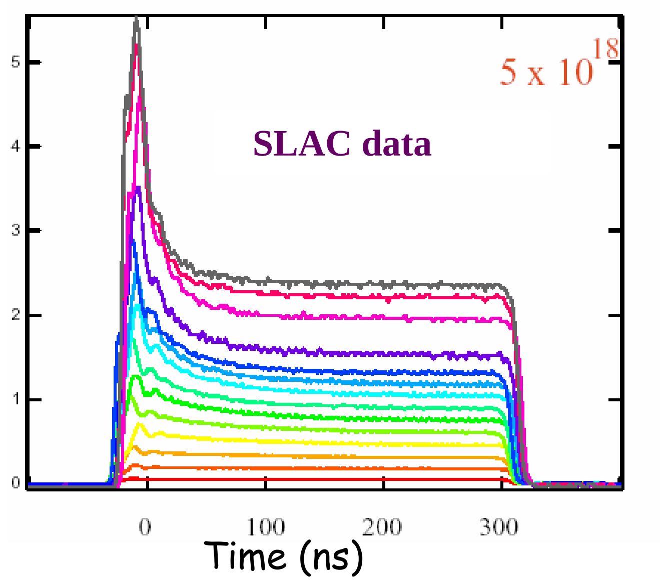
Surface Charge limit

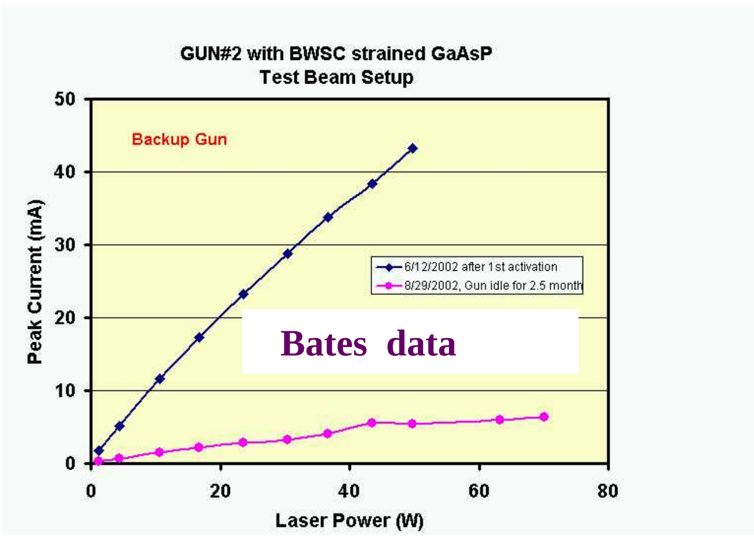
- Charge Output is not proportional to light intensity



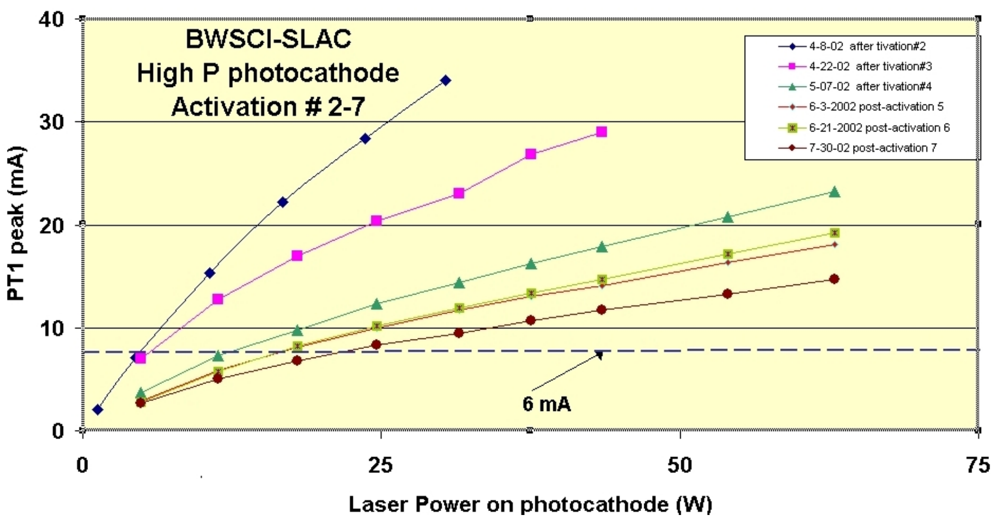
- Methods to overcome or reduce the effect:

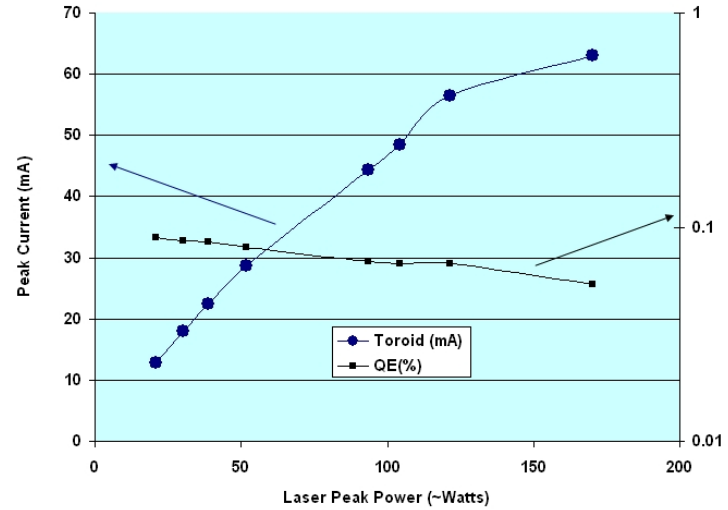
    - superlattice layer (Nagoya, St. Petersburg)
    - highly doped thin layer on top (SLAC-SVT)
    - reduce laser density





Surface Charge limit

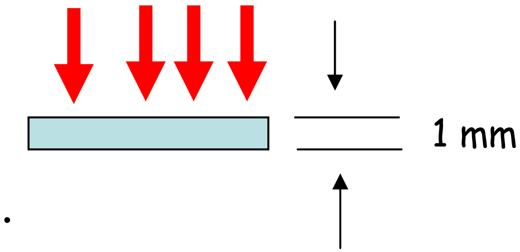




R&D for surface charge limit

- Measure QE at these high peak currents.
- Monitor QE vs time and vacuum conditions
- Must do this in an actual gun chamber and photocathode.
- Improve vacuum condition in the gun.

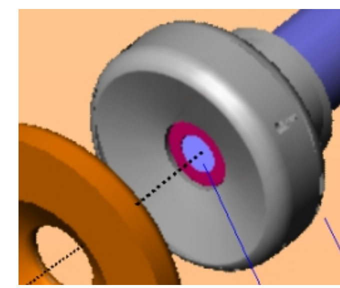
Photocathode heat dissipation:



- With 0.5-2 kW laser power illuminating a 3 cm^2 surface.

k= 0.75 W/cm.C° for GaAs., 0.1 cm thick.,

ΔT = 20-80°. Too much for an NEA surface with mono layer of Cs atoms.

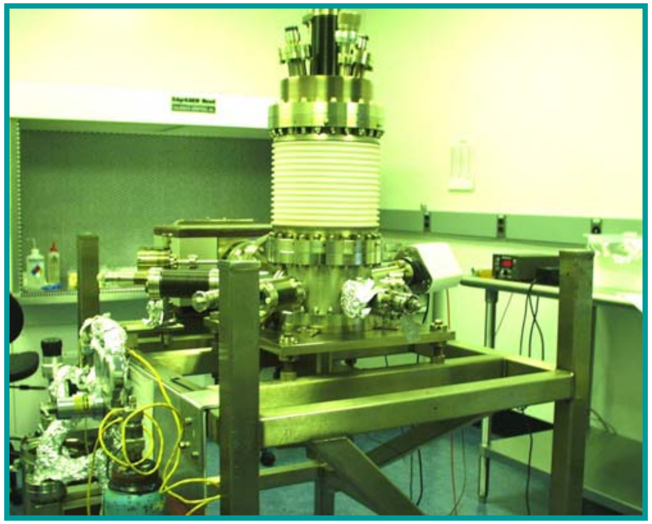


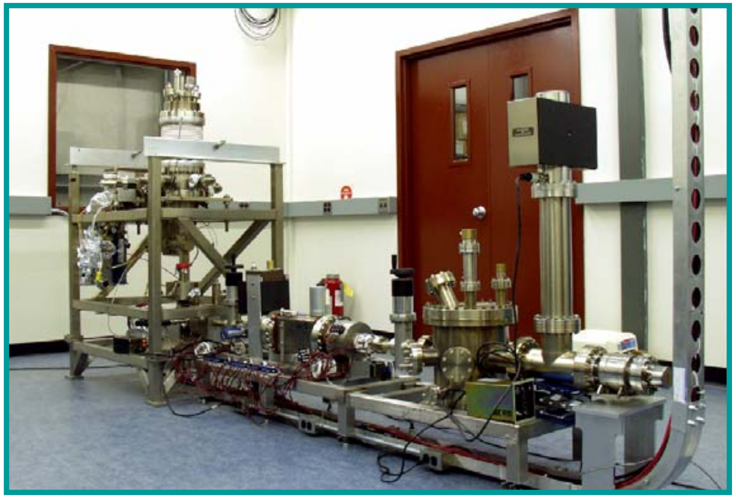
- With a molybdenum cathode stock, L=30 cm, S=0.5 cm^2, ΔT will be too high across the stock without active cooling.
- Must have active cooling (flowing liquid or cold gas) to remove heat from photocathode and the cathode stock.

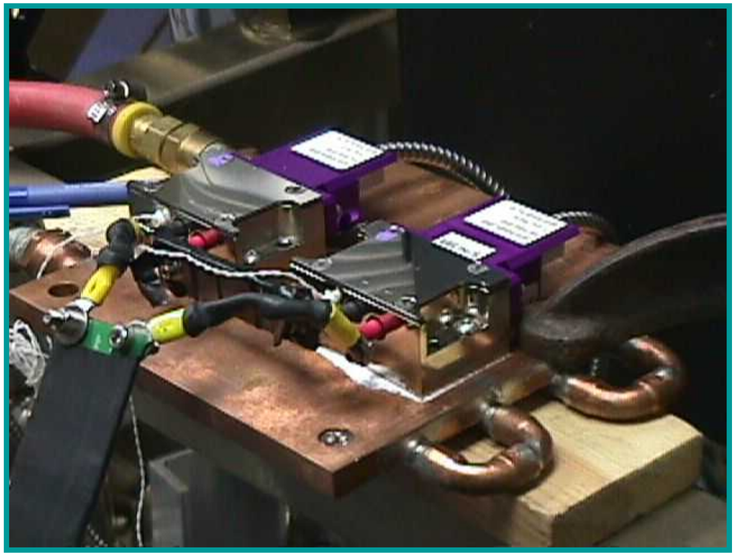
R&D for heat removal from cathode:

- Design and construct actively cooled cathode
- Test cathode assembly with cooling using high power diode lasers while monitoring the UHV conditions.

Bates polarized Source facility







MIT-Bates polarized source infrastructure

- 60 keV test beam setup w/ Wien filter and Mott polarimeter
- Triple gun systems
- 20 MeV accelerator w/ transmission polarimeter
- Class 1000 and 100 cleanrooms and benches
- Atomic hydrogen cleaning apparatus
- **Lasers:**
  - Ar pumped Ti:sapphire 7 W peak
  - Flashlamp pumped Ti:sapphire ~ 1kW peak
  - High power diode array lasers 100 W
  - Ar laser: 30 W
  - Verdi: 5 W
  - Mode locked Ti:sapphire:

MIT-Bates polarized source expertise

- MIT-Bates is undergoing a transition from a user facility to a Research and Engineering laboratory, maintaining the core expertise in vital areas including polarized source.
- Bates personnel and infrastructure are well suited to tackle the required polarized source R&D for eRHIC.
- Much of the polarized source R&D is common to the ring-ring and linac ring version of eRHIC.

Active collaboration in progress with other institutions:

- J-Lab pol. source group: Load lock technology and 500 keV Gun (CEBAF, FEL and ELIC)
- Cornell-ERL photoinjector: 500 kV DC gun under consideration.
- SLAC: photocathode development.

Proposed initial polarized source R&D for Linac-Ring eRHIC

- Starting in FY2006, as part of the Bates R&E Lab we propose an R&D effort in polarized source for eRHIC that require 2.5 FTE/yr for the next three years. This work should concentrate on design and construction of large area photocathode guns to address:
  - ❑ Heat removal at high laser powers.
  - ❑ Charge limit effects on superlattice samples
  - ❑ High voltage performance (500 kV)
  - ❑ High peak and average currents

  Implement these designs in a load lock gun system
- Proposed capital equipment for this work is ~ $1.5M
- This effort is complementary to the work required for the ring-ring polarized source.

Summary

- The linac-ring option of eRHIC requires a challenging polarized source with 450 mA average current..
- With a dedicated FEL as the drive laser for the polarized source illuminating a 3 cm^2 photocathode, and scaling the demonstrated existing gun performances, these high average currents seems feasible.
- R&D efforts are essential in several fronts in polarized source technology (scaling law, average and peak current, lifetime, surface charge limit, heat dissipation…)
- MIT-Bates has the expertise and infrastructure to pursue R&D in polarized sources for the linac-ring and ring-ring options of eRHIC. This initial R&D will require 2.5 FTE for three years (FY06-08) with a capital equipment budget of ~ $1.5M.